THE ABSORPTION OF IONS BY LIVING AND DEAD ROOTS

H. V. Johnson

It is a well-known fact that roots often produce an acid or an alkaline reaction in solutions of neutral salts.[1] This might be ascribed to the excretion of acid or alkali by the root or it might be explained on the ground that the root takes up from the solution more kations than anions (making the solution acid) or an excess of anions (making the solution alkaline).

If the root excretes acid or alkali we should expect to find these substances given off in distilled water. A number of investigators have reported that distilled water in which roots are placed frequently becomes acid.[2]

The writer has confirmed this and has found that after thorough boiling (to drive off CO_2) the reaction may still be acid to litmus. In these experiments the writer employed roots of corn and took care not to allow the seeds to come into contact with the solution.

The execretion of alkali by roots may be considered doubtful, although the excretion of alkali by algae has been reported.

The amount of acidity and alkalinity produced by roots in solutions of neutral salts seems in many cases too great to be accounted for by excretion and it is presumably due to the absorption by the roots of anions or of kations. It is evident that if this is the usual method of absorption it deserves careful investigation. Little attention has so far been paid to the mechanism of this process. It is evident that kations can not be absorbed without anions (or vice versa) for this process would soon be stopped by the resulting electric stresses. It has therefore been suggested that an exchange of ions occurs, the plant giving up a kation for each kation it absorbs, and vice versa. It has

[1] Cf. J. F. Breazeale and J. A. LeClerc, U. S. Dept. Agric. Bur. Chem. Bull. **149**; E. J. Russell, Soil Conditions and Plant Growth, p. 119; R. Meurer, Prings. Jahrb. Wiss. Bot. **46**: 503. 1909; and the literature cited in these articles.

[2] Cf. F. Czapek, Biochemie der Pflanzen **2**: 873. 1905; J. Stocklasa und A. Ernst, Prings. Jahrb. Wiss. Bot. **46**: 73. 1908; R. Meurer, ibid. **46**: 503. 1909; T. Pfeiffer und E. Blanck, Landw. Versuchsst. **77**: 217. 1912, and the literature cited in these articles.

also been pointed out that the same thing may occur in adsorption by various colloids.[3]

It is of course possible that the root gives off hydrogen ions only when it absorbs a corresponding number of other kations. In this case excretion of acid by the root would take place only in solutions of salts. In the same way hydroxyl ions might be exchanged by the root for other anions.

It is evident however that all the facts can be accounted for in another way. The hydrolytic dissociation of neutral salts produces both acid and alkali and, as has been pointed out by Osterhout,[4] if one of these is absorbed by the plant more rapidly than the other the solution must become acid or alkaline.

It is evident that an exchange of ions may occur without altering the reaction of the solution. In such cases the exchange could be detected by an analysis of the solution, before and after the roots have acted upon it. This method has been employed by Meurer[5] and others.

One point which seems to have been lost sight of is that in experiments of this sort the unequal absorption of anions and kations may be due to the dead rather than to the living cells of the root. Thus for example in the extensive experiments of Meurer on beets and carrots the outer layers of the root were cut away by means of a knife. This killed the cells for some distance below the surface so that the solution came into contact with a large mass of dead cells before it penetrated to the living tissue.

It is to be expected that this would affect the results and the writer's experiments show that this is the case. For example the writer has found that live beets removed, from a solution of $CaCl_2$, 41.31 per cent. of the Ca present and 43.74 per cent of Cl, while dead beets removed of 44 per cent of Ca and only 26.25 per cent of Cl (Table I, averages). Carrots gave a similar result, the live plants removing 9.65 per cent of Ca and 7.8 per cent of Cl while the dead removed 53.87 per cent of Ca and 28.57 per cent of Cl (Table I, averages).

[3] von Bemmelen, Zeitschr. Anorgan. Chem. **23**: 321. 1900; Höber, Physikalische Chemie der Zelle und der Gewebe, S. 239, 1914.

[4] Science n. ser. **36**: 571. 1912.

[5] Meurer, R. Prings. Jahrb. Wiss. Bot. **46**: 503. 1909.

TABLE I

Beet, Carrot and Turnip in Solution of $CaCl_2$

	Duration of Experiment in Days	Gram Ionic Conc. of Ca		Gram Ionic Conc. of Cl		Per Cent Ca Removed	Per Cent Cl Removed
		At Start	At End	At Start	At End		
Beet...............	8	.0222	.0188	.0422	.0345	15.3	18.2
Alive............	17	.0222	.0170	.0422	.0319	23.4	24.4
Alive............	8	.0222	.0178	.0422	.0340	19.8	19.4
Alive............	39	.0222	.0088	.0422	.0170	60.4	59.7
Alive............	17	.0206	.0130	.039	.0228	36.78	41.47
Alive............	17	.0206	.0094	.039	.0147	54.53	62.31
Alive............	17	.0206	.0104	.039	.0191	49.34	50.96
Alive............	26	.0206	.0087	.039	.0156	57.57	60.00
Alive............	14	.0206	.0094	.039	.0128	54.53	67.18
					Average	41.31	43.74
Dead (chloroform).	3	.0222	.0109	.0422	.0270	50.9	36.0
Dead (formalin)...	9	.0221	.0139	.0420	.03505	37.1	16.5
					Average	44.0	26.25
Carrot							
Alive............	9	.0222	.0198	.0422	.0382	10.8	9.5
Alive............	11	.0222	.0203	.0422	.0396	8.5	6.1
					Average	9.65	7.8
Dead (chloroform).	3	.0222	.0123	.0422	.0333	44.6	21.1
Dead (chloroform).	4	.0222	.0116	.0422	.0312	47.7	26.1
Dead (formalin)...	9	.0221	.0131	.0420	.0341	40.7	18.8
Dead (formalin)...	17	.0206	.00704	.039	.02235	65.56	42.56
Dead (formalin)...	17	.0206	.00602	.039	.0256	70.78	34.31
					Average	53.87	28.57
Turnip							
Dead (chloroform).	2	.0221	.0169	.0420	.0350	23.5	16.6

In the writer's experiments uninjured beets or carrots were placed in the solution (the top projecting out of the liquid) and allowed to remain for the period indicated. The concentration of ions was determined before and after the roots were placed in the solution. The Ca was determined by precipitating with ammonium oxalate, igniting and weighing as CaO; the Cl was titrated with 0.1 M $AgNO_3$, using potassium chromate as indicator. The amount of experimental error is shown by comparing the determinations of the concentrations of the two ions at the beginning of the experiment as given in the table (if there were no experimental error the gram ionic concentration of Cl would be exactly twice that of Ca).

In subsequent experiments corn was germinated in tap water. When the roots had reached a length of one or two inches and were in active growth, so that no dead cells were observable, they were placed

TABLE II

Roots of Corn in Solution of $CaCl_2$

Lot	Roots of White Field Corn	Duration of Experiment in Days	Gram Ionic Conc. of Ca		Gram Ionic Conc. of Cl.		Per Cent Ca Removed	Per Cent Cl Removed
			At Start	At End	At Start	At End		
1	Alive..............	15	.0221	.0192	.0420	.01823	58.4	56.6
2	Alive..............	14	.0226	.0117	.0429	.0231	48.2	46.1
3	Alive..............	14	.0226	.0135	.0429	.02536	40.3	40.9
4	Alive..............	7	.0226	.0107	.0429	.0220	52.6	48.7
5	Alive..............	7	.0226	.0079	.0429	.01693	65.0	60.5
						Average	52.9	50.56
6	Dead (killed by boiling then in $CaCl_2$ and formalin).....	5	.0221	.0133	.0420	.0254	39.8	39.5
7	Dead (from lot 1, in $CaCl_2$ and formalin).............	4	.0221	.0186	.0420	.03496	15.8	16.8
8	Dead (from lot 2, in $CaCl_2$ and formalin).............	3	.0226	.0221	.0429	.04053	2.2	5.5
9	Dead (from lot 3, in $CaCl_2$ and formalin).............	3	.0226	.0186	.0429	.03313	17.7	22.8
10	Dead (in tap water; then in $CaCl_2$ and formalin)........	3	.0226	.0175	.0429	.03386	22.5	21.1
11	Dead (in tap water; then in $CaCl_2$ and formalin)........	3	.0226	.0182	.0429	.13513	19.5	18.1
12	Dead (from lot 4; in $CaCl_2$ and formalin)	2	.0226	.0192	.0429	.03926	15.0	8.5
13	Dead (from lot 5; in $CaCl_2$ and formalin)	2	.0226	.0210	.0429	.04003	7.1	6.7
						Average	17.45	17.37
	Roots of Sweet Corn							
14	Dead (in tap water; then in $CaCl_2$ and chloroform)......	5	.0206	.00597	.039	.0136	71.0	65.13
15	Dead (in tap water; then in $CaCl_2$ and chloroform)......	5	.0206	.00606	.039	.0135	70.56	65.38
16	Dead (in tap water; then in $CaCl_2$ and chloroform)......	5	.0206	.00784	.039	.0168	61.66	56.92
17	Dead (in tap water; then in $CaCl_2$ and chloroform)......	5	.0206	.00918	.039	.0189	55.41	51.54
						Average	64.66	57.59

in $CaCl_2$. (The seeds were not allowed to come into contact with $CaCl_2$.) In some cases sufficient chloroform or formalin was added to the $CaCl_2$ to kill the roots and the results were then compared with those

obtained with living roots. In experiments with sweet corn the dead roots took up somewhat more Ca than Cl but this was not true of white field corn (Table II, averages). A single experiment on dead turnips gave a result similar to that obtained with sweet corn (Table I).

It is therefore evident that in some cases the presence of dead cells has a very marked influence on the results. It should be borne in mind that even when all the root cells are alive at the beginning of the experiment some of them may be killed by the solution while the experiment is going on. For this reason the writer employed $CaCl_2$ in his experiments, as calcium salts are in general less toxic than the other common salts of the soil. In long experiments it seems advisable to employ, whenever possible, balanced (or non-toxic) solutions for this purpose.

LABORATORY OF PLANT PHYSIOLOGY,
HARVARD UNIVERSITY.

[The JOURNAL for April (**2**: 157–198) was issued 13 May 1915.]